Grays Harbor Shell Mitigation Project
2003 Annual Crab Production Report

FINAL REPORT

April 2004

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Executive Summary

The three new 2003 shell plots: 2003 Up, 2003 Down, and 2003 East) yielded 0.91, 0.64, and 0.47 million J4 crabs respectively during summer 2003. All three new plots outperformed all old shell plots; the 1995 Island plot had highest productivity of the pre-2003 plots with 0.24 million crabs. Total production for all plots sampled during the 2003 season was 2.81 million crabs, the third highest in the 14 year history of the project. Total production in 2000 was 3.42 million J4 crabs and 1992 yielded 3.23 million crabs. This brings the cumulative sum of J4 individuals produced by Grays Harbor mitigation plots to 20.89 million since its inception in 1990.

Production rate per square meter of habitat created averaged of 30 crabs $\bullet m^{-2}$ for the three new plots created in spring 2003, while half of the old shell plots also exceeded the initial mitigation target of 10 crabs $\bullet$ m^{-2}. Shell cover still correlates extremely well with production rate, particularly shell cover values for May and June when crab densities are the highest..

Hemigrapsus oregonensis densities were extremely low and thus interspecific competition for refuge spaces seems to be a diminishing factor predicting juvenile Dungeness crab success on mitigation plots. Eelgrass distribution and coverage does not help explain the trends in production data at this point, but a longer timeline of data may help predict where optimal shell placement sites will be.

Plot-specific mortality rates do not explain the production variation among new shell plots for the 2003 season, although in general survival rates were better on new habitat. Mortality rates for summer 2003 were lower than average, with only 46% of early benthic phase crabs surviving on new shell habitat (9 of 10 previous years when new shell was created had better survival) and only 36% surviving on old shell habitat (9 of 11 years when old shell was sampled had better survival). Settlement patterns seem to be the key to the production results seen this year: The highest performing plot, 2003 Up, had densities of over 70 crabs $\bullet$ m^{-2} in May, and almost 150 crabs $\bullet$ m^{-2} in June. The 2003 Down plot, yielding the second highest number of J4 crabs, had over 60 crabs $\bullet$ m^{-2} in May and almost 80 crabs $\bullet$ m^{-2} in June (as well as the best survival rate of all plots sampled this year). The 2003 East plot had densities of about 170 crabs $\bullet$ m^{-2} in May dropping to just over 60 in June, but survival was only 42.6%, the lowest of the three new

shell plots. While no statistically significant differences are evident as yet, elevation of the shell habitat may partially explain the settlement preferences as the elevation range of the data and timeline extends. The plot with the highest elevation this year was the 2003 Up plot, which produced the most crabs per square meter of habitat.

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Scope and Objective

The primary objective of summer 2003 sampling efforts was to obtain production estimates for the new 2003 shell mitigation plots as well as for old shell plots constructed in previous years. ('Old' refers to any plot sampled one year or more after original placement of oyster shell on the mud surface.) In order to obtain production estimates of J4 juveniles, monthly densities and size composition of juvenile Dungeness crab as well as percent shell cover data were collected for all plots which had a significant percentage ($\geq 20\%$) of shell as surface substrate and thus was likely to serve as protective habitat for juvenile crab. Other factors expected to influence productivity, such as abundance of *Hemigrapsus oregonensis* and presence of eelgrass were surveyed and recorded as well.

Background

History

Although periodic dredging of the shipping channel through Grays Harbor estuary has taken place since the early 1900's, controversy over Dungeness crab *(Cancer magister)* mortality due to dredge entrainment did not become an issue until the late 1980's. The plan, authorized in 1986, to widen and deepen the shipping channel into Aberdeen as part of the Grays Harbor Navigation Improvement Project (McGraw et al. 1988, Wainwright et al. 1992, Dinnel 1996), brought environmental and economic concerns to a head. Mitigation was deemed necessary by state and federal agencies and in 1990, the US Army Corps of Engineers adopted the current mitigation strategy, which includes attempts to avoid and minimize the impact, as well as compensation for the impact. Despite efforts by the U.S. Army Corps of Engineers (COE) to select gear type and plan timing of operations to minimize impacts, an estimated 26% of resident crab in the path of the hopper dredge become entrained (Wainwright et al. 1992). Construction of intertidal juvenile habitat by depositing inert oyster shells on the surface of the mudflat

(Fig. 1) was initiated in 1990 to increase survival rates during the first summer of growth (Dumbauld et al. 1993), and thereby "replace" crabs lost to the population by increasing survival through a vulnerable period of their life history. By 1994, South Channel was chosen as the sole location of mitigation efforts after comparisons throughout Grays Harbor estuary. Several years of efforts in both South Channel and North Bay indicated that shell longevity and productivity, as well as feasibility were greatest in South Channel (Armstrong et al. 1991). The entrainment impact, or estimated crab mortality, is determined for each dredging effort using the Dredge Impact Model (Armstrong et al. 1987, Wainwright et al. 1992), which uses crab population density, the volume of sediment dredged, and a regression function to give the number of crabs lost to the population. After accounting for natural mortality over the time it takes for juvenile crabs to reach legal fishery size, the number of crabs required for impact compensation was reached. Thus the target goal for mitigation efforts became 9 million J4 juveniles after the initial widening and deepening project. This target goal was met in 2001 and the mitigation for construction impacts completed. Mitigation for ongoing operation and maintenance impacts continues, and total crab production since 1990 is over 20 million J4 juveniles.

Figure 1. Creation of shell mitigation habitat, showing barge full of inert oyster shells, deposition of shells at high tide, and new mitigation habitat when exposed after tide has dropped.

Ecology and Life History

Dungeness crab megalopae select flood tide currents as transport mechanisms into Grays Harbor and settle into intertidal areas during late spring and early summer. They subsequently metamorphose into first juvenile instars (J1; 6-9 mm carapace width), with initial densities generally 100-200 crabs per m^2 (Visser and Armstrong 1998). Megalopae and early juvenile instars select shell habitat and survive better in shell than either bare sediment or eelgrass (Fernandez et al. 1993a, Eggleston and Armstrong 1995). Artificial shell mitigation plots and relic deposits of *Mya arenaria* (eastern softshell) serve as important refuge habitat (Armstrong et al. 1992, Palacios 1994) throughout the first summer. By early fall, the juvenile Dungeness crab migrate to subtidal regions and no longer make extensive use of the shell refuge habitat (Gutermuth and Armstrong 1989, Gunderson et al. 1990, Wainwright and Armstrong 1993). By this time, the crabs have reached the J5 instar (20-26 mm carapace width) and shell habitat no longer seems to be crucial refuge habitat for them. Thus the shell mitigation concept is to provide key habitat during this initial vulnerable period in order to increase the number of >25mm carapace width individuals entering the subtidal population.

Hemigrapsus oregonensis colonized the shell mitigation plots after initial construction, to the detriment of juvenile Dungeness crab production (Visser 1997, Dumbauld et al. 2000). For 1992-1997, the typical pattern was high productivity as evidenced by high densities of *Cancer magister* during the initial year after shell plot construction followed by much lower densities of Dungeness crab and much higher abundance of *Hemigrapsus* during subsequent years. Competitive dominance by *Hemigrapsus oregonensis* for refuge space seemed to play the major role in the interaction between the populations (Visser 1997). These competitive interactions, as well as some predation on settling Dungeness megalopae by resident adult *Hemigrapsus*, combined with loss of shell cover due to bioturbation and sediment destabilization by *Neotrypea pugetensis* and *Upogebia californiensis*, led to lost effectiveness of shell plots after their initial year of construction, at least as measured in terms of Dungeness crab productivity. During 1998-2003, the pattern has changed due to an apparent recruitment failure of *Hemigrapsus*. Insufficient data exists to determine whether this is a reproductive failure or a population distribution issue, since our sampling regime is limited to South Channel mitigation plots. While productivity is still greatest on new shell, production per square meter on shell mitigation plots $\geq$ 1 year since construction is much greater than before 1998. The ongoing challenge of the habitat mitigation project is to conduct rigorous sampling to accurately assess the number of juvenile Dungeness crabs being produced by the current habitat, to optimize areas for shell placement in years when appropriate, and to identify patterns in the crab population data that might suggest improved strategies.

Methodology

Field protocol

The standard sampling protocol used in past years was followed to obtain juvenile *Cancer magister* and *Hemigrapsus oregonensis* density and size composition data. After an initial trip to the habitat mitigation plots in early May to determine which sites would be sampled and to measure boundaries, as well as map and mark the plots chosen, sampling trips were made once monthly beginning in early May. The nine plots sampled during summer 2003 were the 1995 Island, 1995 Mainland, 1996/1997 Overlay, 1997 East, 2000 Up, 2000 East, 2003 Up, 2003 Down, and 2003 East plots (Figure 1). Plots are named according to the year they were initially constructed. The three new shell plots were constructed in April by overlaying new oyster shell on top of older shell plots that had lost much of their refuge cover. The 2003 Up plot was constructed on top of the former 1992 plot; the 2003 Down plot was overlaid on the former 1994 plot; and the 2003 East plot was overlaid on the former 2000 Down site. The rationale behind the overlay strategy was to test whether sediment stability, and thus shell longevity, could be improved by utilizing the basement layer of older shell to slow sinkage rates. In general, this overlay strategy has been employed to a greater extent as available space at appropriate tidal heights has been more fully utilized at the South Channel location. Considering the recent decline in resident *Hemigrapsus oregonensis* abundance, the possibility that old shell plots were harboring a population of dominant competitors was minimal, and the risk of increased sedimentation on higher plots seemed more than balanced by the chance of increased sediment stability. Since percent shell cover strongly affects juvenile Dungeness crab survival in the intertidal (Dumbauld et al. 1993), any plot which did not ≥ 20% of shell remaining on the surface was not sampled. These areas yield little to no production of juvenile Dungeness crab and do not merit sampling effort as there is little refuge available to the crabs, and thus extremely low densities.

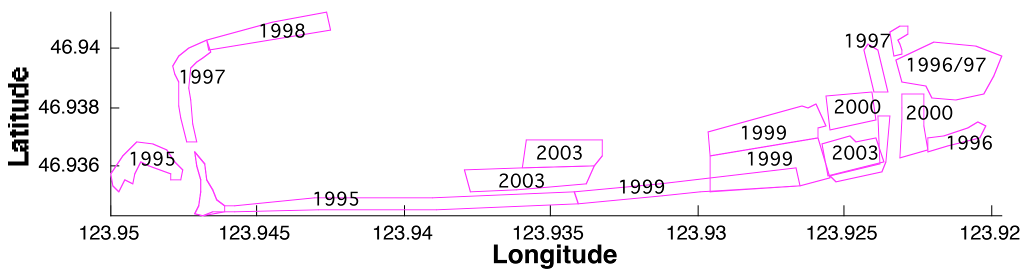


Figure 2. Map of the Army Corps of Engineers shell mitigation plots in South Channel, Grays Harbor, WA, as of summer 2003.

A sampling crew consisting of 6-7 excavation samplers and 2-4 additional shell estimators was taken to the shell mitigation plots by personnel aboard the US Army Corps of Engineers ship Shoalhunter during low spring tides each month (Table 1). About 2 hours before low tide, the crew was delivered to the mudflats to begin sampling. Ten replicate excavation samples were taken monthly from each of the nine plots sampled in 2003 to obtain monthly crab density data for each plot. (Only nine replicates were possible for 1995 Mainland due to decreased size of plot.) Collection of these samples consisted of haphazardly placing a 0.1 m^2 quadrat on a section of 100% shell cover within the plot to be sampled. All shell material from within the quadrat was removed, including all the mud down to 5 cm below the shell layer, and was sorted by hand and seived through a 3 mm mesh screen (Figure 2). All crabs retained by the screen were placed into bags to be identified to species and measured back on the ship after the tide rose. Crabs were identified to species, measured to the nearest 0.1 cm carapace width, and recorded. For *Hemigrapsus oregonensis,* gender and state of ovigery for females was also recorded.

Table 1. Sampling dates, approximate times, and estimated tidal heights for data collection during summer 2003 at South Channel crab mitigation sites. There were three sampling dates each month; the initial two tides in May were used for field site preparation.

Date	Low tide time	Low tide height
15-May	6:56 AM	-2.9
16-May	7:45	-3.6
17-May	8:33	-3.9
18-May	9:21	-3.7
19-May	10:09	-3.2
13-June	6:39	-3.5
14-June	7:29	-4.0
15-June	8:17	-4.1
13-July	7:14	-3.6
14-July	8:01	-3.6
15-July	8:46	-3.3
11-August	6:57	-2.8
12-August	7:41	-2.7
13-August	8:22	-2.4

Note: Times and heights given are based on actual tides at Aberdeen, WA (Port of Grays Harbor Tide Tables), with approximate corrections of –0:28 minutes and –0.8 feet applied. Standard corrections for Westport are -0:56 minutes and -1.6 feet and the South Channel site is about half way between Westport and Aberdeen.

Figure 3. Sampling procedure, showing digging of 0.1 m^2 sample, quadrat full of shell material, sorting technique of rinsing and visual inspection for animals, and crabs typically found in samples (large *Hemigrapsus oregonensis*, and J1 and J5 Dungeness instars).

Estimates of amount of refuge area available within each plot were necessary in order to translate the crab density data into total number of crabs produced. Total amount of refuge space was computed by multiplying plot size by percent shell cover. These percent shell cover estimates were taken by 4 to 6 observers visually studying each of ten marked subplots (20m x 20m) throughout each of the nine plots sampled in 2003. (Only nine subplots were surveyed in the 1995 Mainland plot due to space constraints. The amount of shell remaining above the surface of the mud and therefore representing refuge space available to the juvenile crabs was recorded (Figure 3). Thus, the overall monthly shell cover estimate for each plot was based on 40-60 individual independent estimates, resulting in a mean and a standard deviation as input for the production model.

Figure 4. Variation in shell habitat quality, showing approximately 100%, 50%, and 5% coverage of mud surface.

Although shell provides the optimal refuge habitat for very young juvenile Dungeness crabs, both as evidenced by survival rates and by habitat preference experiments (Fernandez et al. 1993), eelgrass *(Zostera marina)* serves as habitat and provides some protection as well. Part of the mitigation strategy in Grays Harbor has been to avoid placing shell in areas where eelgrass flourishes in order not to disturb any natural refuge function within the estuary. On plots where eelgrass beds flourish, shell placement is therefore patchy (Figure 4). Percent cover estimates for eelgrass have been added to the mitigation sampling scheme in recent years so that trends in eelgrass coverage can be tracked. One theory to be tested when possible is that eelgrass propagation, distribution, and abundance may be enhanced by the shell placement program by contributing sediment stability. Because eelgrass supports much lower densities of crabs, and particularly because it is a naturally occurring phenomenon rather than a direct result of mitigation efforts, estimates of eelgrass coverage are for information purposes only and do not factor into the production model at all. Hopefully production estimates for mitigation sites represent only crabs produced as a direct result of the artificial habitat created by mitigation efforts and are directly additive with natural production from other habitats and do not alter the natural functioning of the estuary.

Figure 5. Example from the 2000 East plot, showing patchiness of habitat and proximity of shell and eelgrass habitats.

Data analysis

Data from the field notebooks were entered into Microsoft Excel spreadsheets, analyzed using the production model originally developed by Armstrong et al. (1995) and modified by Visser and Armstrong (1998). This model applies a plot-specific mortality function to the crab density data over an instar-based molt interval. Density of J2 instars are used as input for the model since J1 density is extremely variable, especially at the beginning of the summer depending on how the timing of specific settlement events correlates with the timing of the initial sampling period in any given year. When J3 instars are present at the first sampling date, they are treated as early settlers and inputted into the model as well, using the same mortality function computed for that specific plot, but over the shorter period of time a J3 instar takes to reach the J4 size class. The mortality rates for each plot are computed each year by fitting an exponential function to the declining Dungeness crab density data for each field season. In some years the data require computing the mortality function without the initial settlement peak of J1 instars (J2 mortality), although this was not the case for 2003 data. Multiplying the density of surviving crabs by the effective refuge area (the product of total habitat area constructed and percent shell cover) gives the number of crabs produced by each plot for each month over the summer. The J4 instar serves as the accepted production unit, as per agreement by COE and agency personnel historically. By the time the crabs reach J5 instars, they are no longer at as great a risk and begin to move to subtidal areas, making their intertidal densities a poor measurement of their population abundance. Thus, the computed mortality rate is applied over a 35 day interval for J2 instars and a 20 day interval for J3 instars, the time it takes for each instar to reach the fourth juvenile instar, J4 or 16-19 mm carapace width. Results in the form of production of crabs per plot and annual comparisons, crab density and instar composition, and shell cover, as well as eelgrass abundance and mortality rates are presented and discussed. Since intertidal juvenile Dungeness crab densities are less than 5 crabs • m^{-2} and generally zero in areas with no shell or eelgrass refuge, all crabs produced on the shell mitigation plots are attributed to the mitigation efforts. The sampling regime does not test the possibility that the mitigation plots attract crabs that may otherwise be settling elsewhere within the Grays Harbor system. Nor does it consider the carrying capacity of the subtidal channels and whether or not enhanced production of intertidal juveniles actually translates through the next stages of life history into increased number of legal adults entering the fishery three to four years later.

Results and Discussion

2003 Production

Sampling during summer 2003 resulted in production estimates of 2.8 (+ 0.35) million crabs. Of this total, 2.0 million was from the new shell placed in April 2003, and 0.8 million crabs were produced on the five old shell plots sampled (Table 2). Early settlement played a minor role this year compared to past years, attributable mostly to the timing of the spring low tide series in 2003 relative to the chosen sampling dates. As usual, most of the production resulted from the June sampling series, with 62.55% of the total production coming from June data. May was next highest, with 26.66% of the total 2.8 million crabs produced coming from May data. July and August were much lower, with 8.82% and 7.39%, respectively. If serious budget constraints ever arise in management of crab mitigation efforts in Grays Harbor, foregoing the August sampling date may be a reasonable modification to consider.

Table 2. Summary data for the 2003 production model; output is production of J4 instars.

Habitat	Month	J2 /m2	sd	Mortality	Area	Shell	sd	Production	Early	Total Prod	sd
1995 Island	May	9	14	0.0211	19051	0.73	0.34	59690	45082	236086	43918
	June	24	13	0.0211	19051	0.60	0.32	131313			
	July	0	10	0.0211	19051	0.69	0.35	0			
	August	0	0	0.0211	19051	0.72	0.35	0			
1995 Mainland	May	23	29	0.0217	7479	0.57	0.22	45969	19004	82062	28056
	June	9	9	0.0217	7479	0.44	0.19	13731			
	July	2	12	0.0217	7479	0.48	0.19	3357			
	August	0	0	0.0217	7479	0.54	0.21	0			
1996/1997	May	20	22	0.0390	42662	0.24	0.15	53299	52793	158006	40793
	June	21	10	0.0390	42662	0.21	0.16	47519			
	July	2	13	0.0390	42662	0.20	0.15	4395			
	August	0	0	0.0390	42662	0.33	0.17	0			
1997 East	May	26	28	0.0268	8671	0.28	0.24	24321	21576	64520	23360
	June	20	35	0.0268	8671	0.25	0.21	16987			
	July	2	17	0.0268	8671	0.24	0.23	1635			
	August	0	0	0.0268	8671	0.32	0.30	0			
2000 Up	May	34	20	0.0368	13912	0.47	0.17	60868	24708	99836	29652
	June	11	13	0.0368	13912	0.31	0.14	13034			
	July	1	11	0.0368	13912	0.32	0.11	1226			
	August	0	0	0.0368	13912	0.48	0.15	0			
2000 East	May	11	13	0.0280	13695	0.61	0.30	34664	35909	146672	22891
	June	23	16	0.0280	13695	0.51	0.32	60276			
	July	5	16	0.0280	13695	0.49	0.26	12678			
	August	1	3	0.0280	13695	0.61	0.31	3146			
2003 Up	May	13	14	0.0242	20145	0.70	0.12	78608	148749	913082	36129
	June	114	42	0.0242	20145	0.63	0.13	620843			
	July	11	30	0.0242	20145	0.62	0.12	58951			
	August	1	3	0.0242	20145	0.69	0.11	5930			
2003 Down	May	11	22	0.0174	25422	0.59	0.19	89898	200399	640893	67188
	June	42	35	0.0174	25422	0.49	0.16	281816			
	July	7	22	0.0174	25422	0.47	0.20	45551			
	August	3	9	0.0174	25422	0.56	0.22	23229			
2003 East	May	30	19	0.0244	16126	0.63	0.21	129359	104778	474541	60694
	June	46	43	0.0244	16126	0.53	0.23	167225			
	July	21	91	0.0244	16126	0.44	0.22	62871			
	August	3	5	0.0244	16126	0.50	0.23	10308			
Total										**2815697**	**352682**

The breakdown of total crab production over the four month sampling season by plot shows that the 2003 Up plot produced the greatest number of crabs, followed by the other two new plots: 2003 Down then 2003 East (Figure 5). These production differences are not due to plot size as the 2003 Down plot was the largest (Table 2), yet performed worse than the 2003 Up plot. Among old shell plots, the oldest, the 1995 Island plot, produced the most crabs (0.24 million).

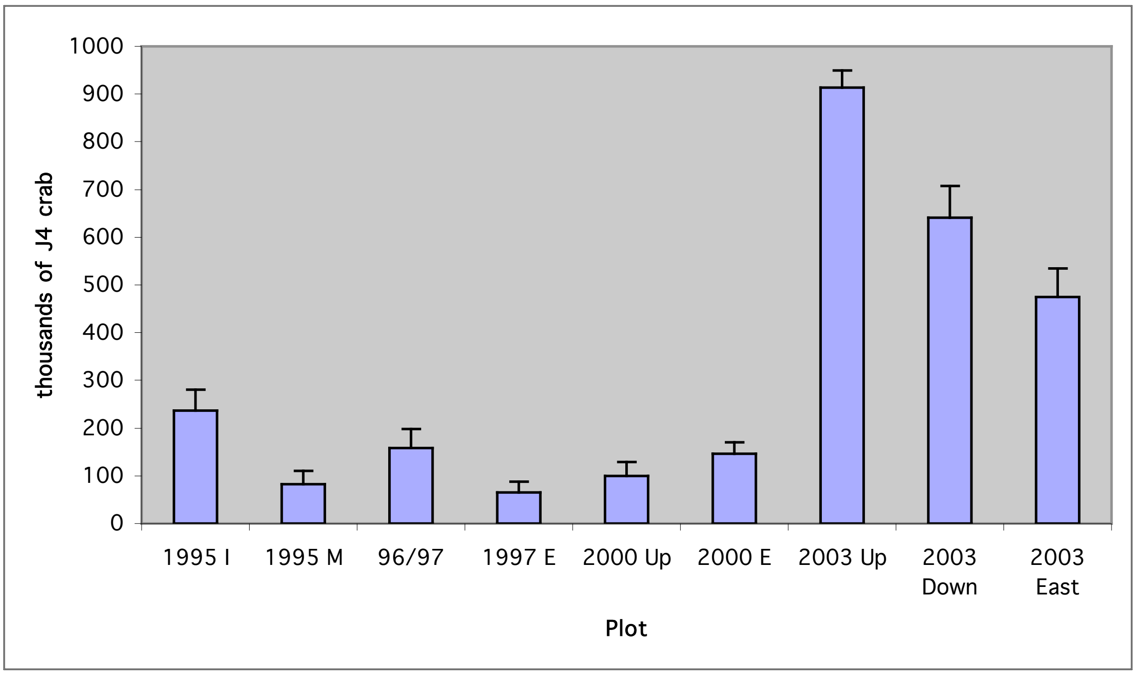


Figure 6. Annual crab production during summer 2003 by each of the nine plots sampled this season.

Cumulative production values

Total production of juvenile Dungeness crab from the South Channel shell mitigation plots is almost 21 million J4 individuals thus far (Table 3). About 2/3 of this production is from plots in their initial year after construction (68%) while the remaining 32% is from old plots one or more years post-construction. The same information is shown in graphical form (Figure 6) where the contribution of new and old shell to each year's production total can be compared by bar color.

Table 3. Annual production by new and old shell plots sampled since the beginning of the shell mitigation project. Note that unlike other tables, 'year' here is year of sampling, not year of plot construction (so 2.8 million crabs were produced by all nine new and old plots sampled in 2003).

Year	New	Old	Total	st.dev.
1990	109,710	N/A	109,710	29,172
1991	204,984	117,987	322,971	77,615
1992	3,226,965		3,226,965	670,204
1993	N/A	44,222	44,222	27,042
1994	1,633,038	0	1,633,038	701,685
1995	2,054,273	124,945	2,179,217	788,633
1996	684,584	328,064	1,012,648	136,052
1997	275,729		275,729	
1998	235,167	1,320,398	1,555,565	287,290
1999	1,164,115	254,838	1,418,953	167,137
2000	2,503,377	913,513	3,416,889	285,964
2001	N/A	2,382,476	2,382,476	408,102
2002	N/A	493,780	493,780	100,899
2003	2,028,516	787,181	2,815,697	352,682
Total	**14,120,458**	**6,767,404**	**20,887,860**	**4,032,477**

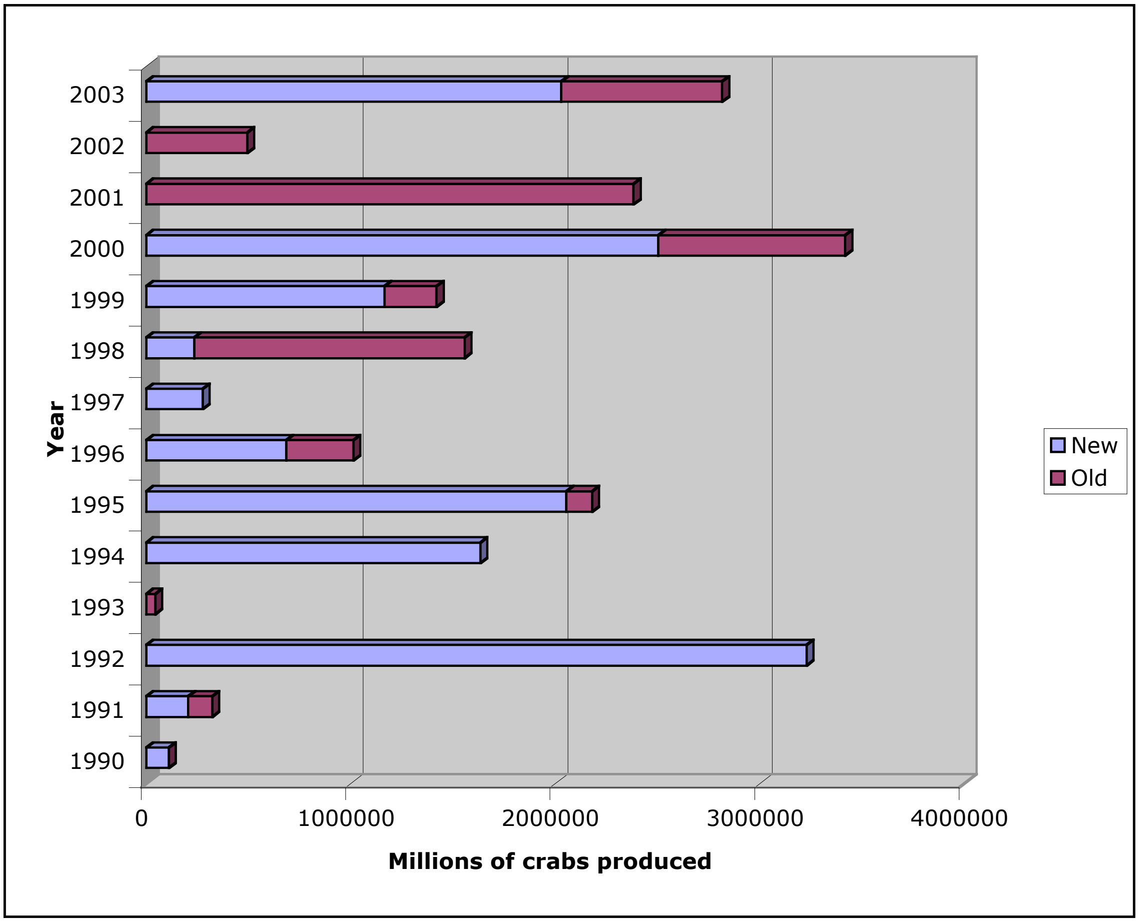


Figure 7. Cumulative production of the shell mitigation project by year. Colors show amount of each year's annual total attributable to shell placed in that year versus sampling of older shell placed in previous years. No new shell habitat was created in 1993, 2001, or 2002, which is why there are no blue portions of the bars for these years.

Production rate

While new plot elevation data, from surveys taken since the 2003 shell placement occurred, are not available at this time, approximate elevations for the new shell can be estimated from 2002 elevation data. These estimates indicate that the correlation suggested last year (Visser 2002) between productivity • m^{-2} and elevation of individual plots may hold (Figure 7). Adding the approximate elevation data for the three new 2003 plots to the graph strengthens the r^2 for the relationship (new data takes it from 0.27 to

0.37). The 2003 Up plot produced 72 crabs • m^{-2}, which is the second highest rate realized in the fourteen year history of shell mitigation monitoring in Grays Harbor.

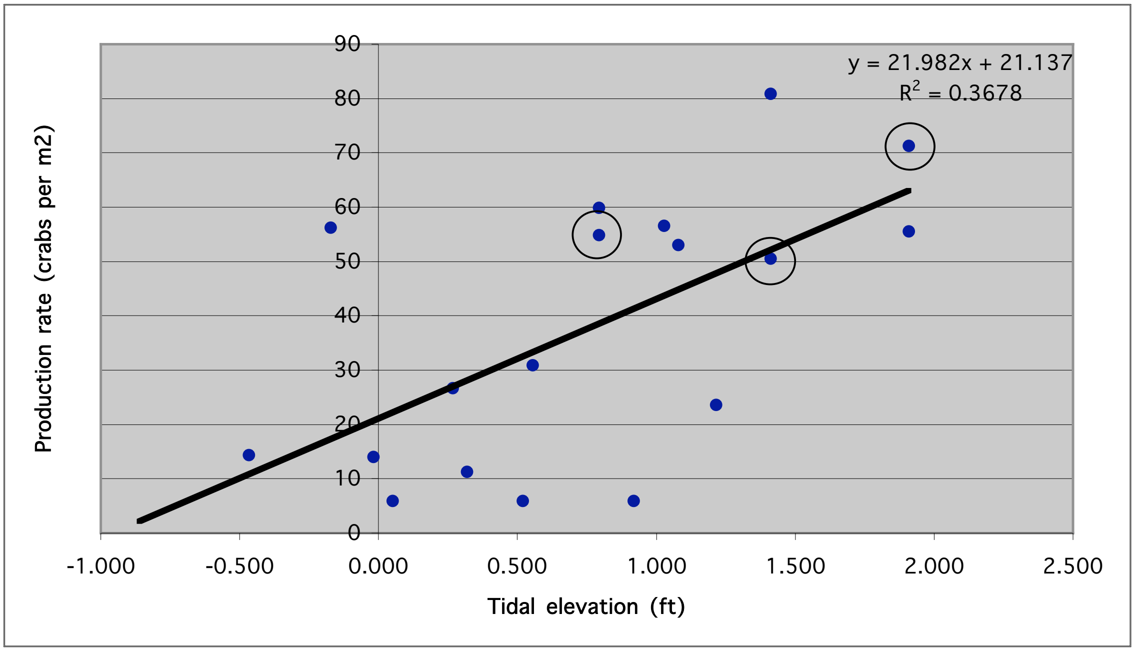


Figure 8. Plot elevation within the intertidal zone versus shell plot productivity for new shell (productivity during the initial year of construction only). Elevations for the 2003 data (circled) are approximate as exact data have not yet been made available.

Average production per unit refuge area, or per meter squared production was over 30 crabs • m^{-2} for new shell during summer 2003, and about 8 crabs •m^{-2} for old shell (Figure 8). While new shell consistently produces more crabs per unit of viable habitat, there is much fluctuation among new plots as a group as well as among old plots as a group (Figure 9). Age of shell alone does not correlate well with productivity rate. Plots vary between 3 and over 50 crabs • m^{-2} in their first year and between 0 and 30 crabs • m^{-2} in subsequent years. The new 2003 shell exceeded the original mitigation goal of 10 crabs • m^{-2}, as did the overall average production for the 2003 season of 17 crabs • m^{-2} for all nine plots sampled. Crab production rates for the two 1995 plots sampled this year were 12 and 11 respectively for the Island and Mainland plots. The 2000 East plot met the original goal with 10.7 crabs • m^{-2}. Only three of the old plots: 1996/1997 (with 3.7 crabs • m^{-2}), 1997 East (with 7.4 crabs • m^{-2}), and 2000 Up (with 7.2

crabs • m^{-2}) failed to meet the original goal of 10 crabs • m^{-2} during 2003 season. These three plots had no more than 50% shell cover by August 2003 (see Figures 10-18), which does not distinguish them from the 1995 Mainland, 2003 Down, or 2003 East plots, where percent shell cover had dwindled to around 50% by August as well. Looking at the average percent shell cover during May and June (the months where greatest crab production is realized) the three poor performing plots (1996/1997, 1997 East, and 2000 Up) were the only plots were shell cover was not over 50% (but rather about 23%, 26% and 39% respectively). All other plots had average shell covers between 50% and 67% during May and June 2003 (Figures 10 –18).

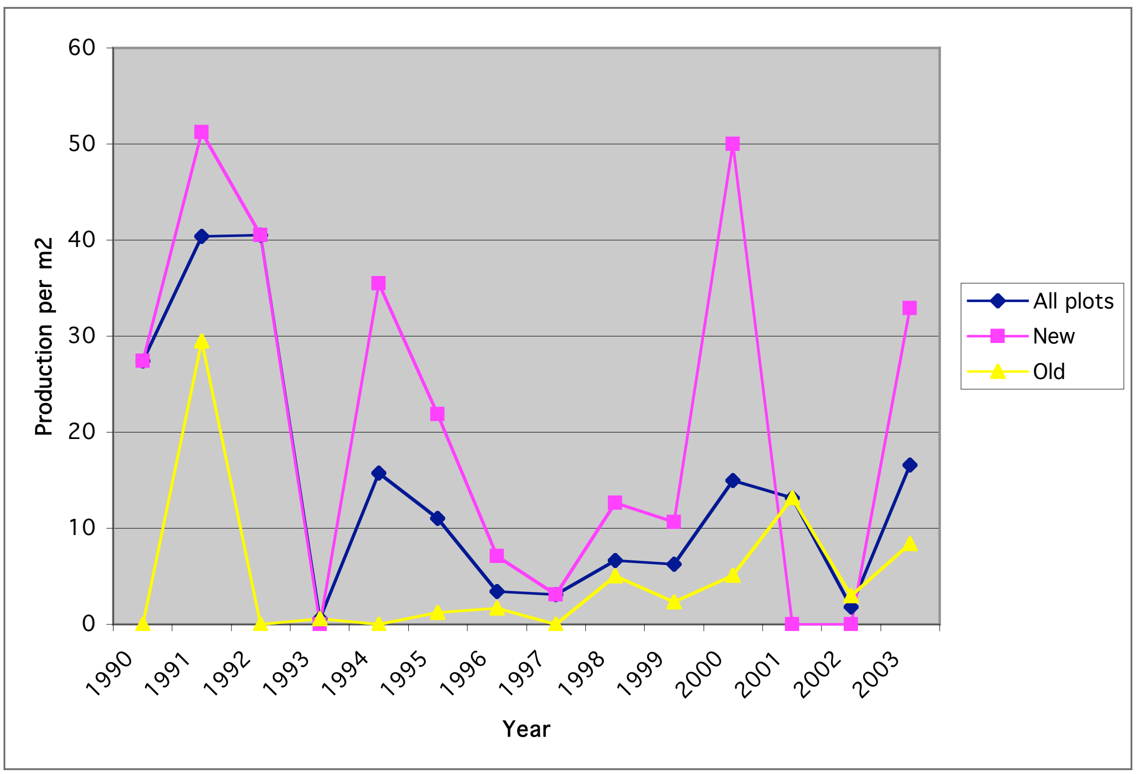


Figure 9. Average production rates (J4 crabs per m^2) for new, old, and all plots over the 14 year history of the mitigation project. Zero values indicate either no new shell placement (1993, 2001, and 2002 new shell) or no sampling effort allocated (1992 and 1997 old shell).

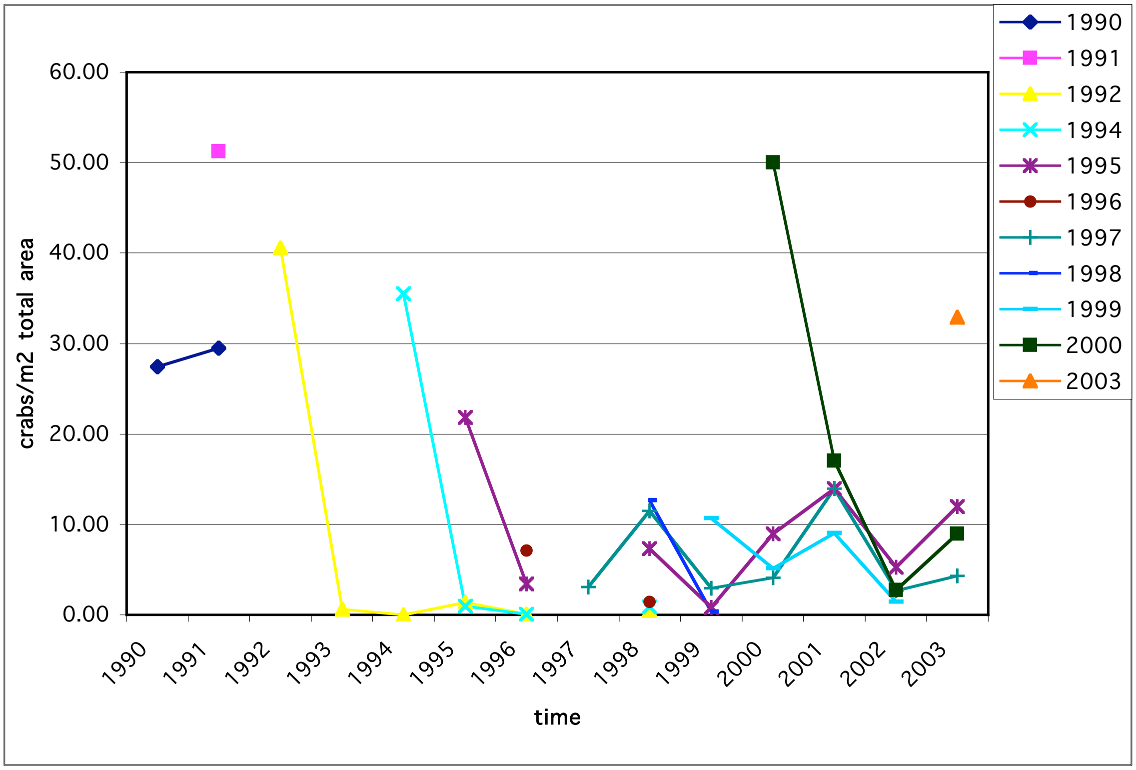
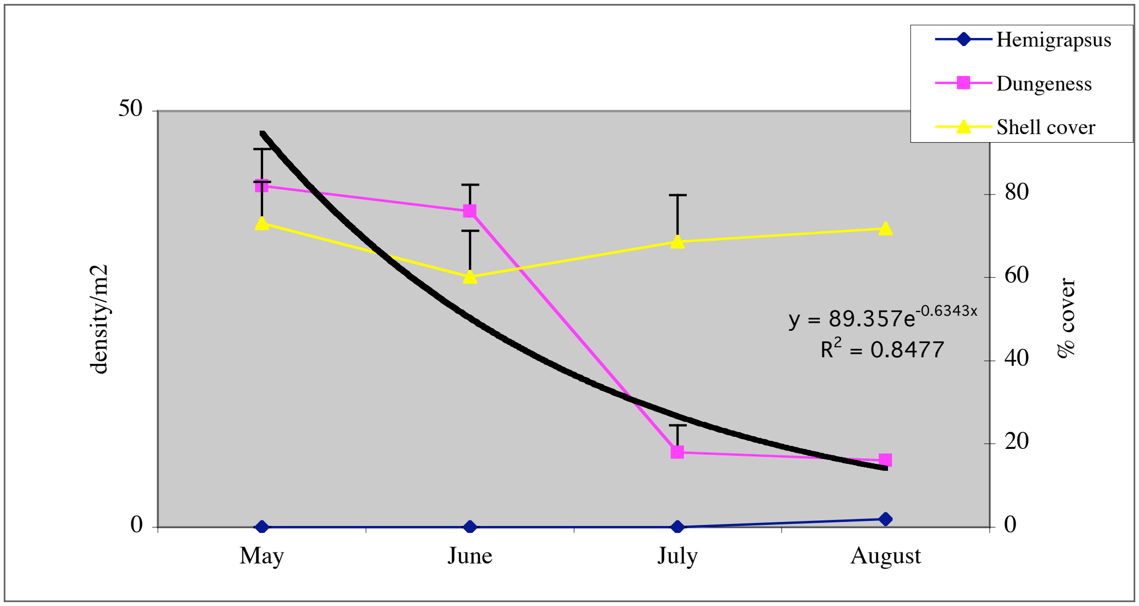


Figure 10. Plot production rate by shell plot created over time for total area of habitat constructed (not corrected for shell cover). The colors and year labels in legend represent shell plots constructed in each year, while the years across the bottom are chronological sampling dates. Thus, green squares show the 2000 shell plot sampled four times: first in 2000 as new shell, then in 2001, 2002, and 2003 as old shell.

Crab density and instar composition

Dungeness crab density data showed the typical trends, with settlement evident in May by high abundance of early J1 instars in the samples (Figures 10-18) and high total crab density. As the crabs grew through larger instar sizes, their density dropped off, showing the natural mortality rate. (Dividing the coefficient for x in the trendline equation by 30 days per month gives the daily mortality rate z used in the production model.) Evidence of settlement of a second cohort late in the sampling season is clear, particularly in the 1997 East (Figure 13) and 2000 Up (Figure 14) plots which show presence of J1 in July as well as the 2000East, 2003 Down, and 2003 East plots (Figures, 15, 17, and 18 respectively) which show that J2 were present as late as mid-August 2003.



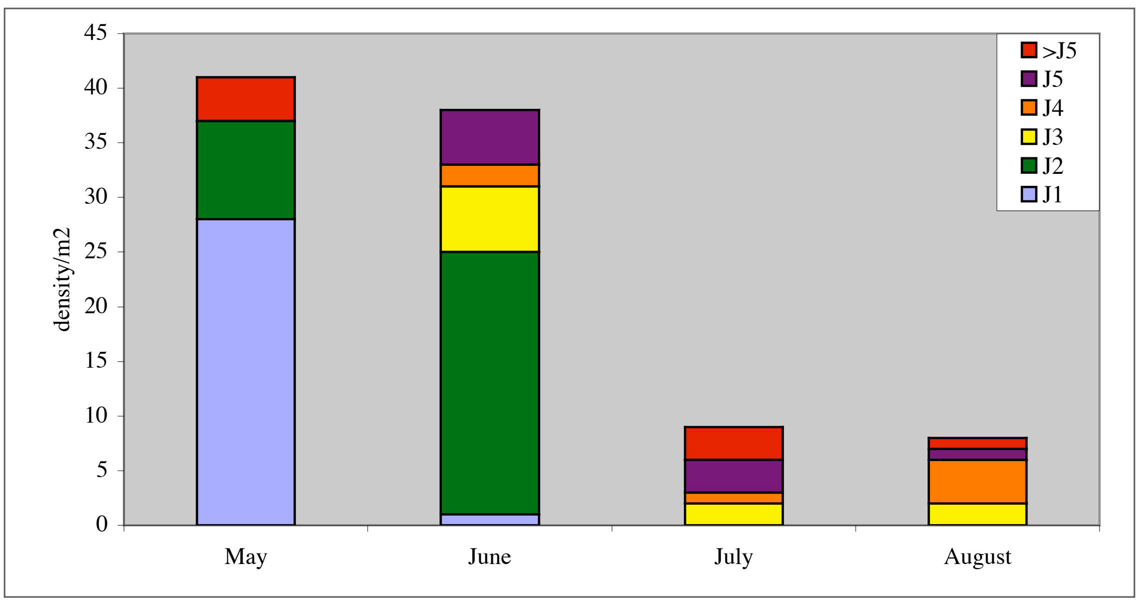
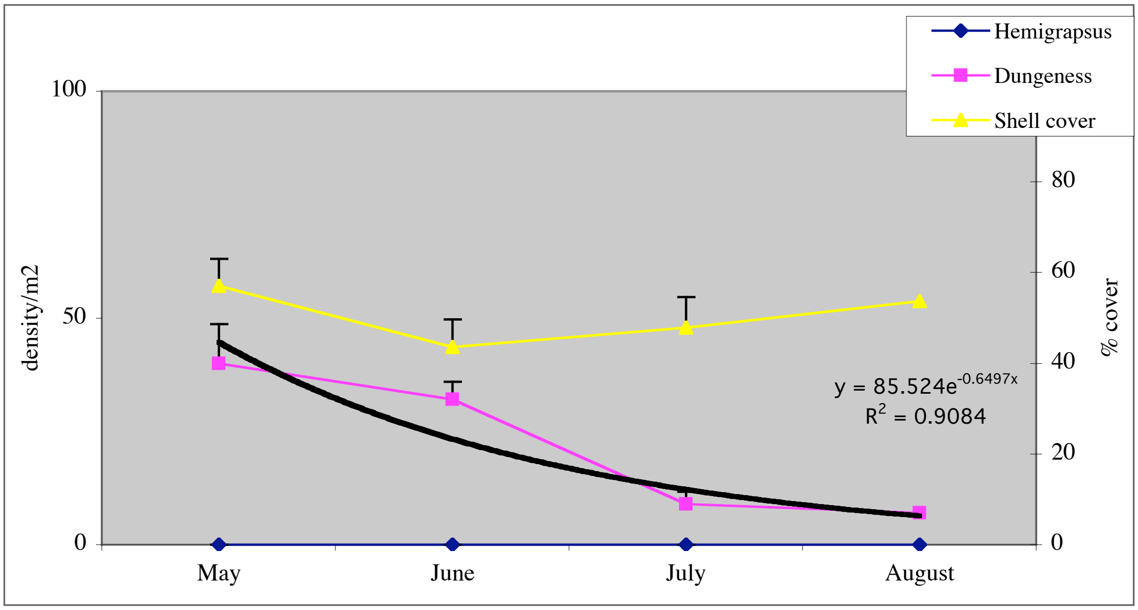


Figure 11. 1995 Island data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



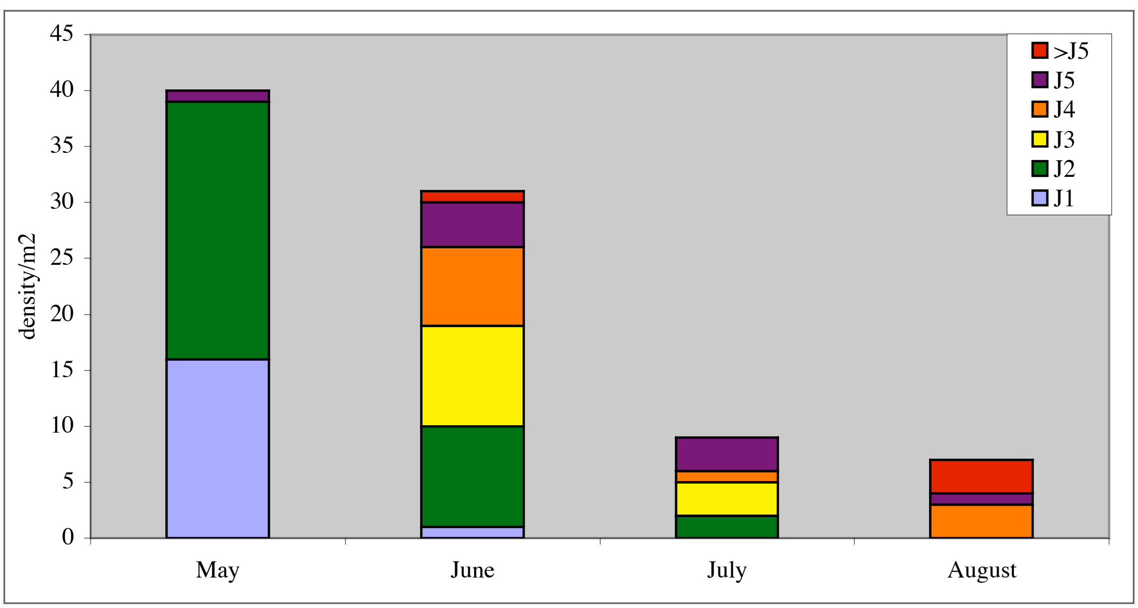


Figure 12. 1995 Mainland data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.

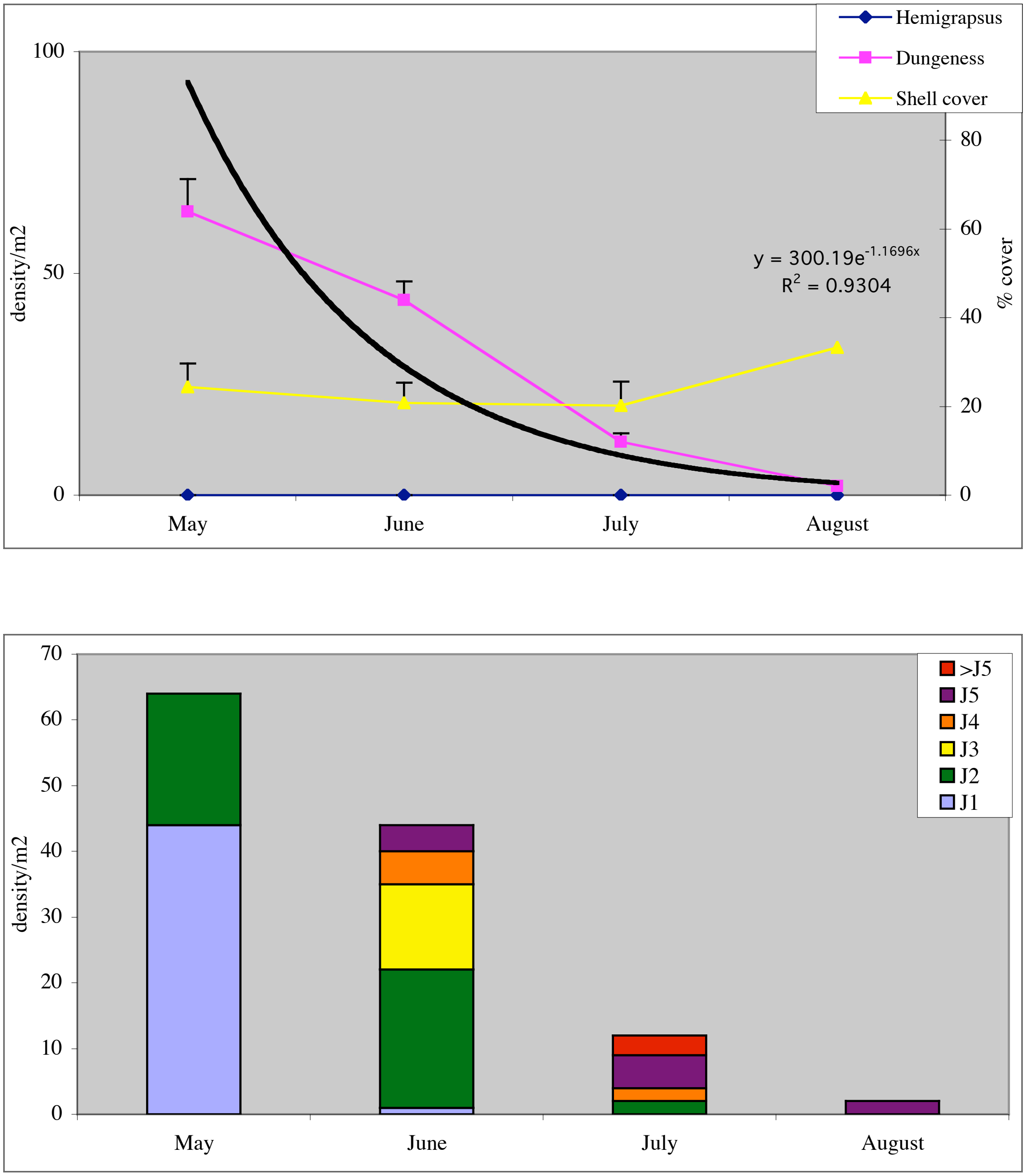
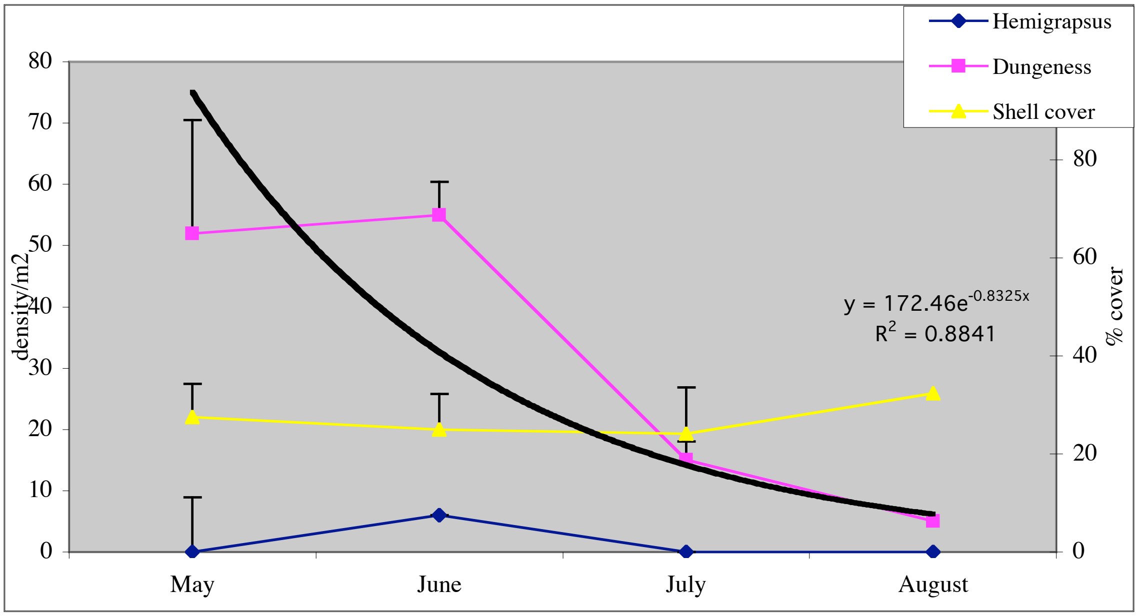


Figure 13. 1996/1997 data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



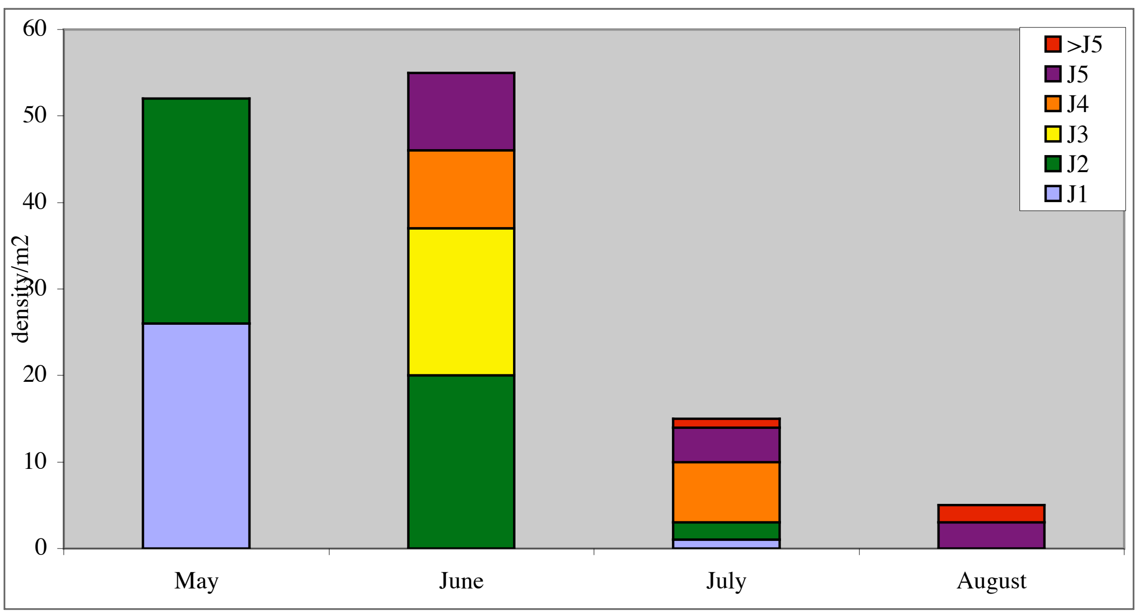


Figure 14. 1997 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.

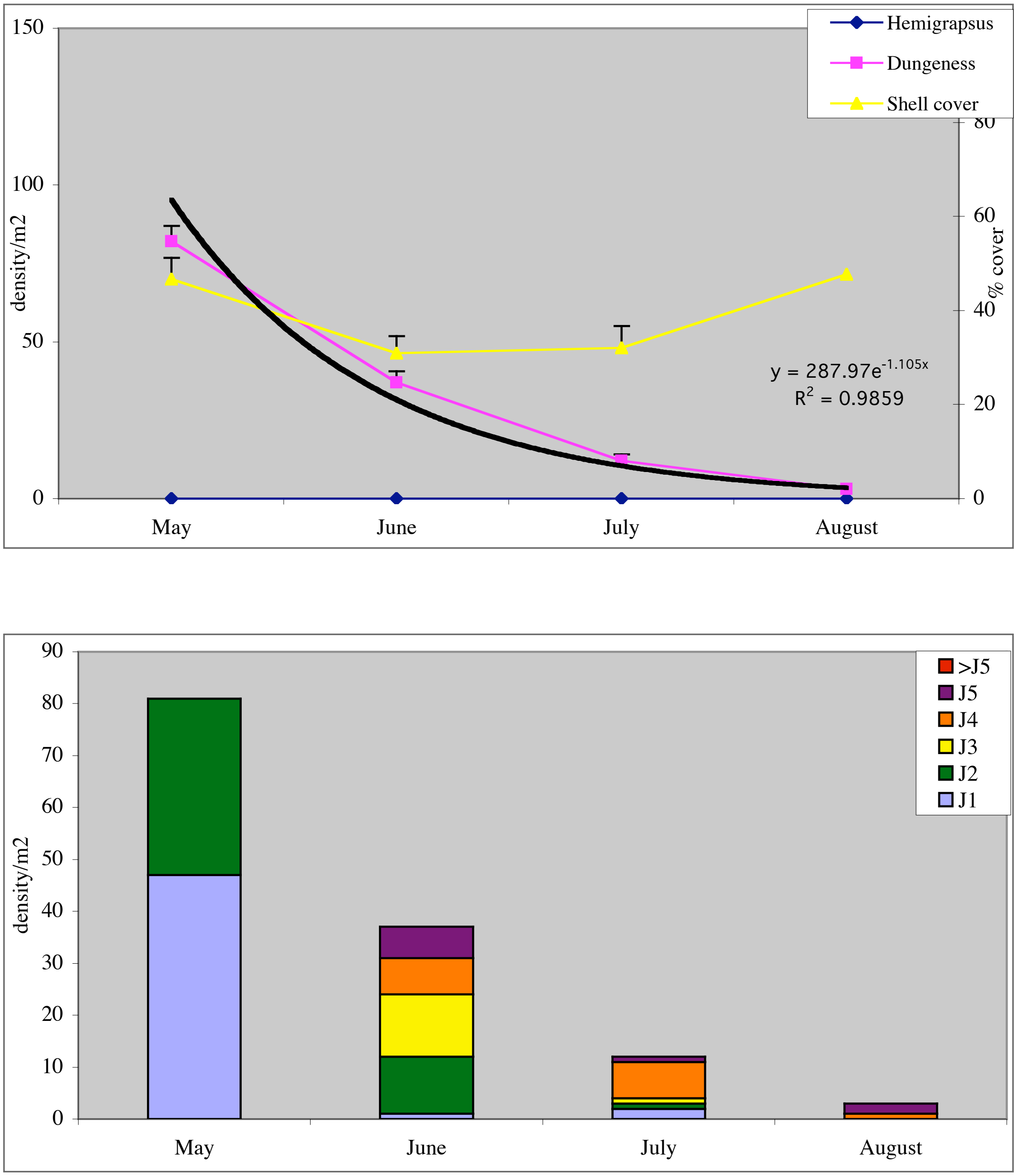
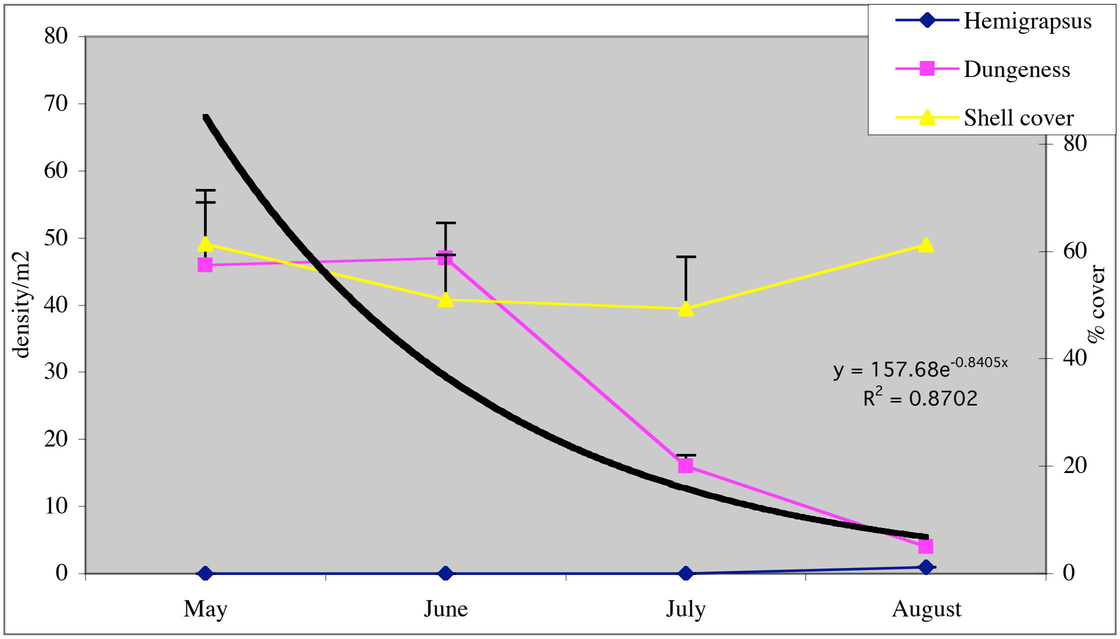


Figure 15. 2000 Up data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



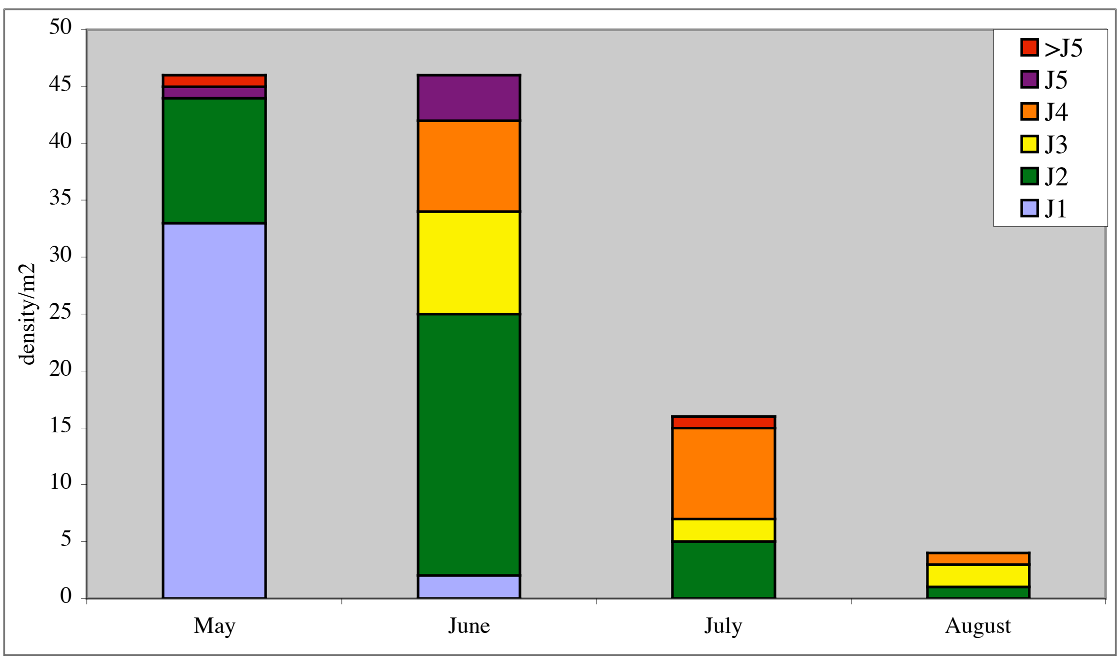
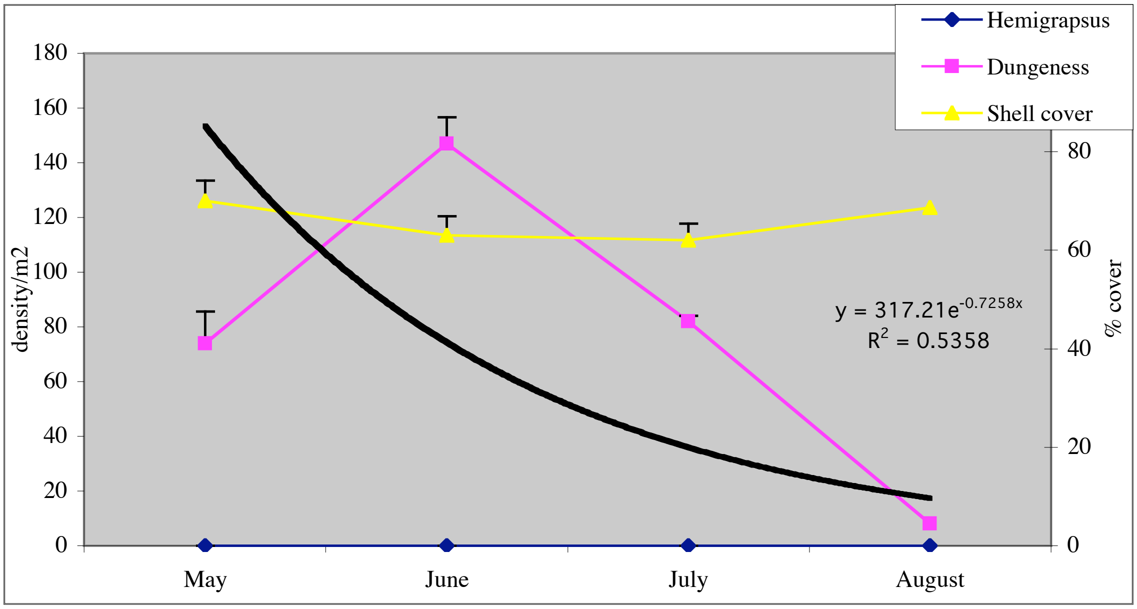


Figure 16. 2000 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



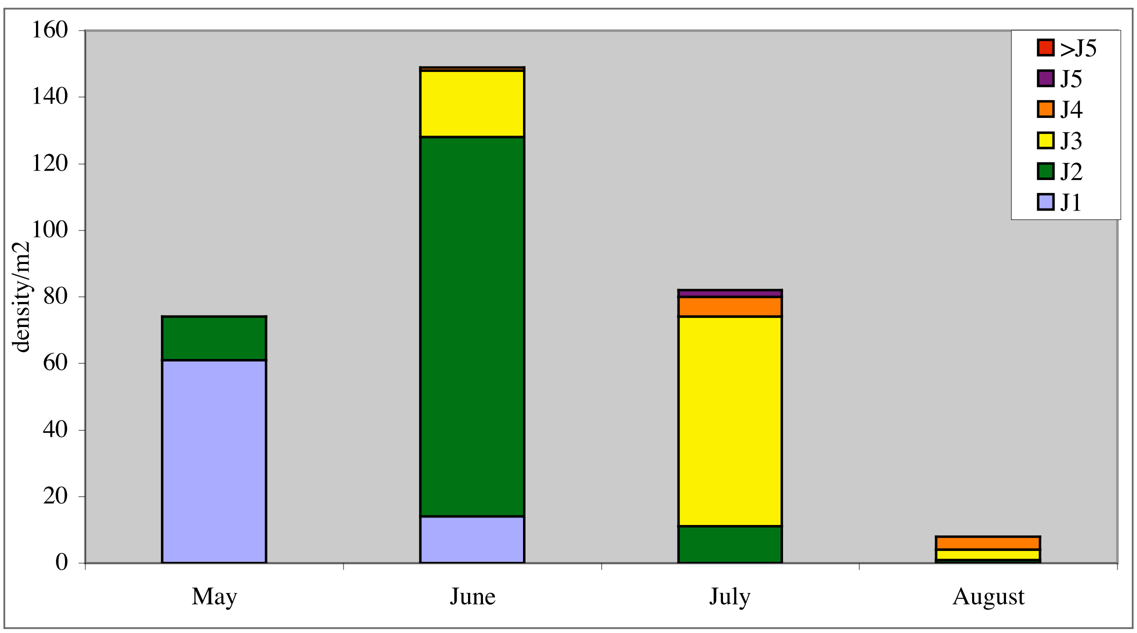
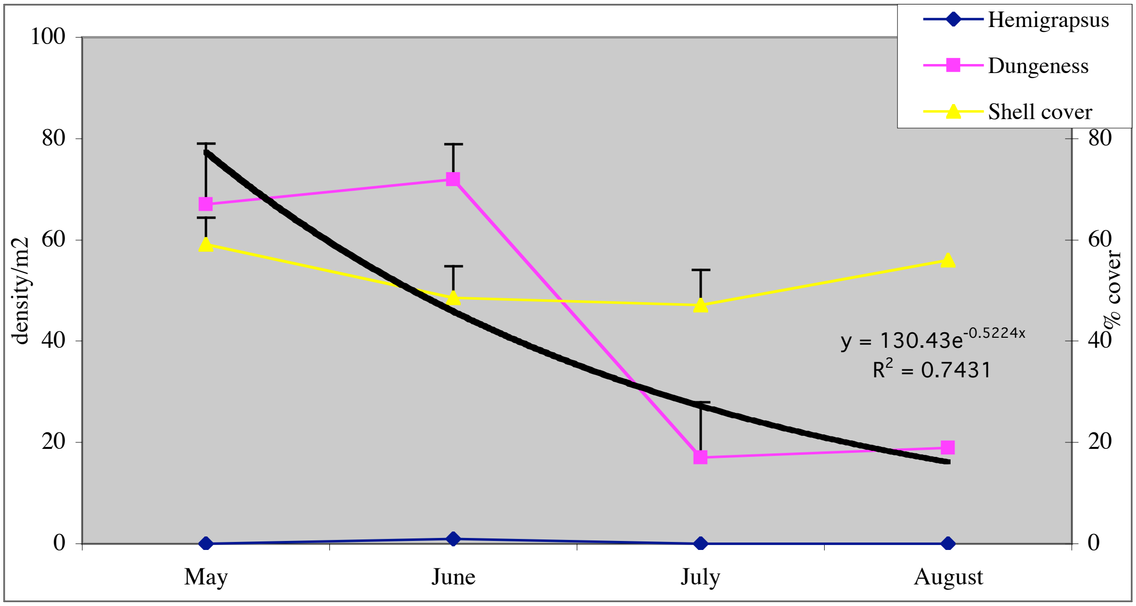


Figure 17. 2003 Up data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



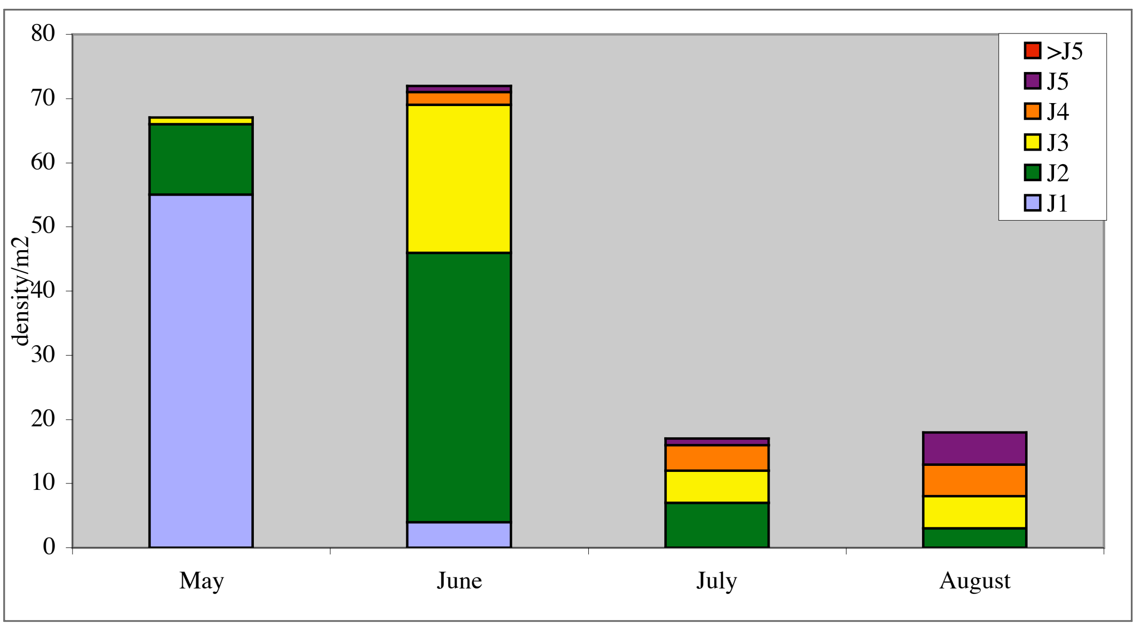
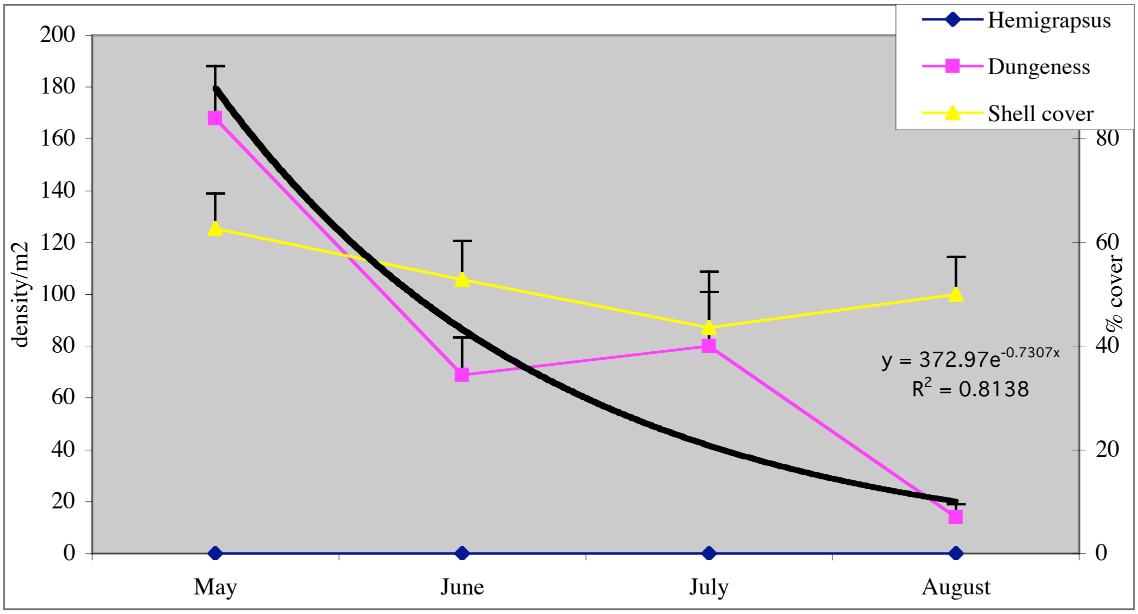


Figure 18. 2003 Down data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



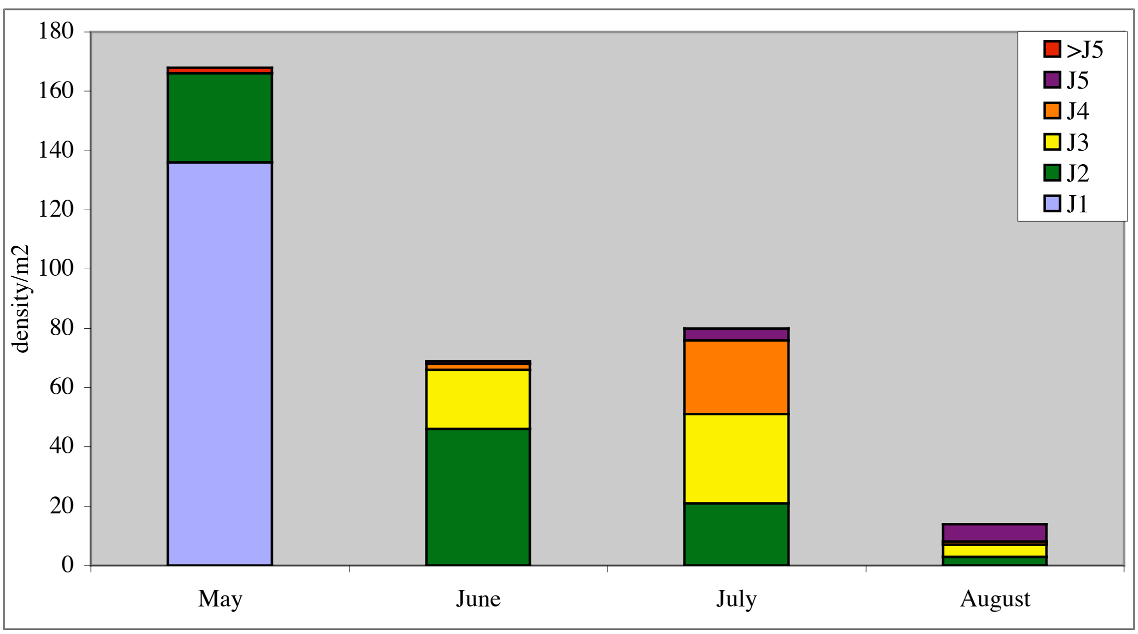
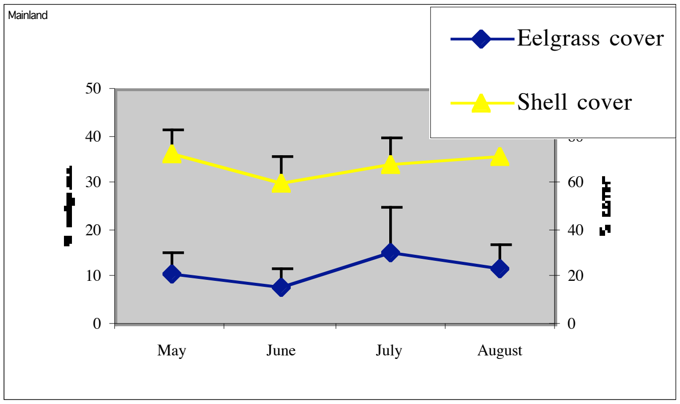


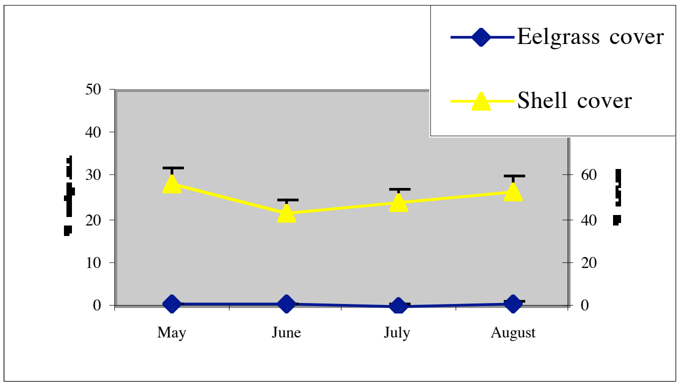
Figure 19. 2003 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for May through August 2003. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.

Hemigrapsus oregonensis densities for the 2003 summer show that the apparent recruitment failure for this population to Grays Harbor that began in 1998 continues to hold. The blue line representing *Hemigrapsus* density is close to zero for all nine plots and all four months sampled in 2003 (Figures 10-18). Thus both 2002 and 2003 sampling years fit into the post-*Hemigrapsus* chapter of mitigation ecology (Visser et al. In press).

Eelgrass data

Average eelgrass cover was always lower than shell cover for all shell plots, staying fairly constant over the summer, but showing a slight increase by August for several shell plots (Figures 19-21). All plots had between 0 and 3% eelgrass cover, except for the 2000 East plot, which averaged 4% eelgrass (Figure 20), and the 1995 Island plot, which averaged 11% eelgrass cover (Figure 19). Although several plots show a slight increase in percent eelgrass by August, there is no strong trend over such a short period. We currently have only two years of complete and replicated eelgrass data for every plot sampled. Longer time trends will be more informative, and hopefully show trends in eelgrass density, abundance, and distribution of patches.





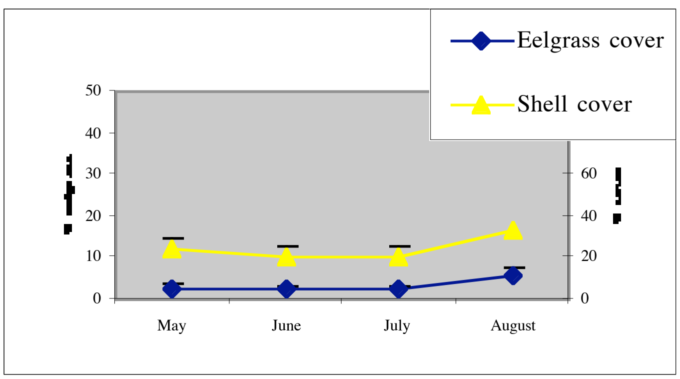


Figure 20. Eelgrass and shell cover data for the 1995 Island, Mainland and 1996/1997 shell plots.

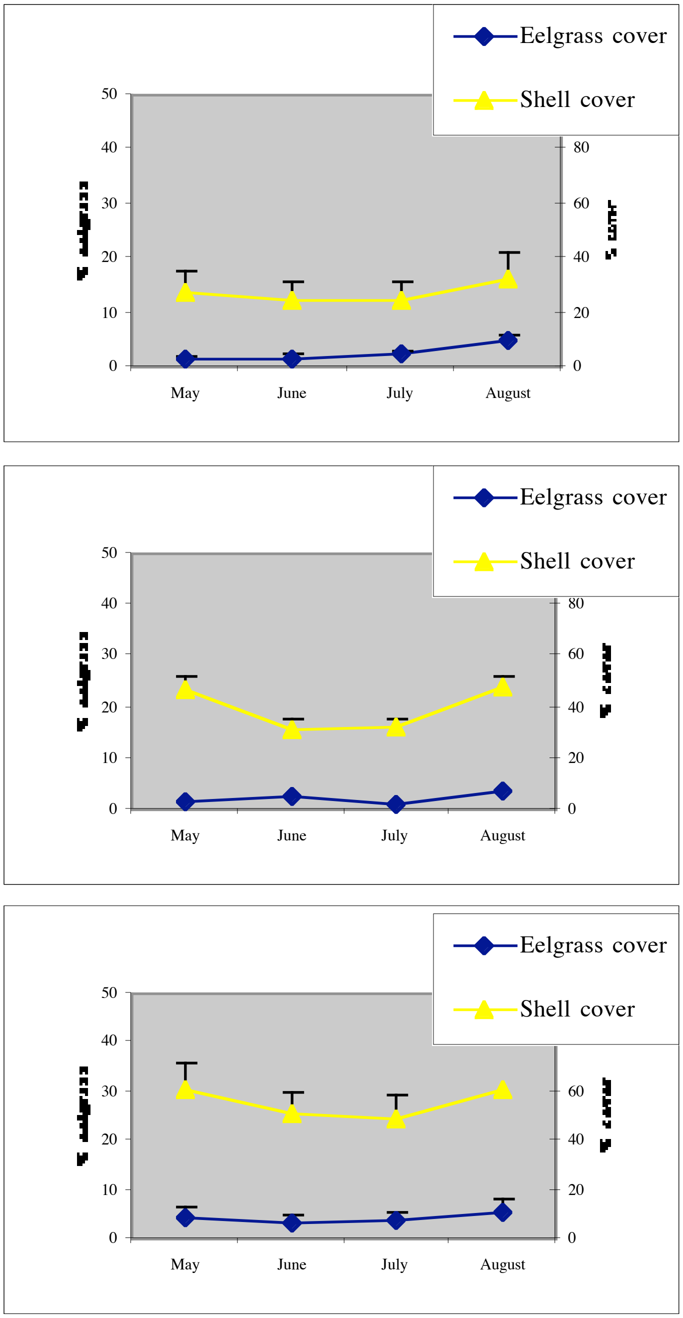


Figure 21. Eelgrass and shell cover data for the 1997 East, 2000Up, and 2000 East shell plots.

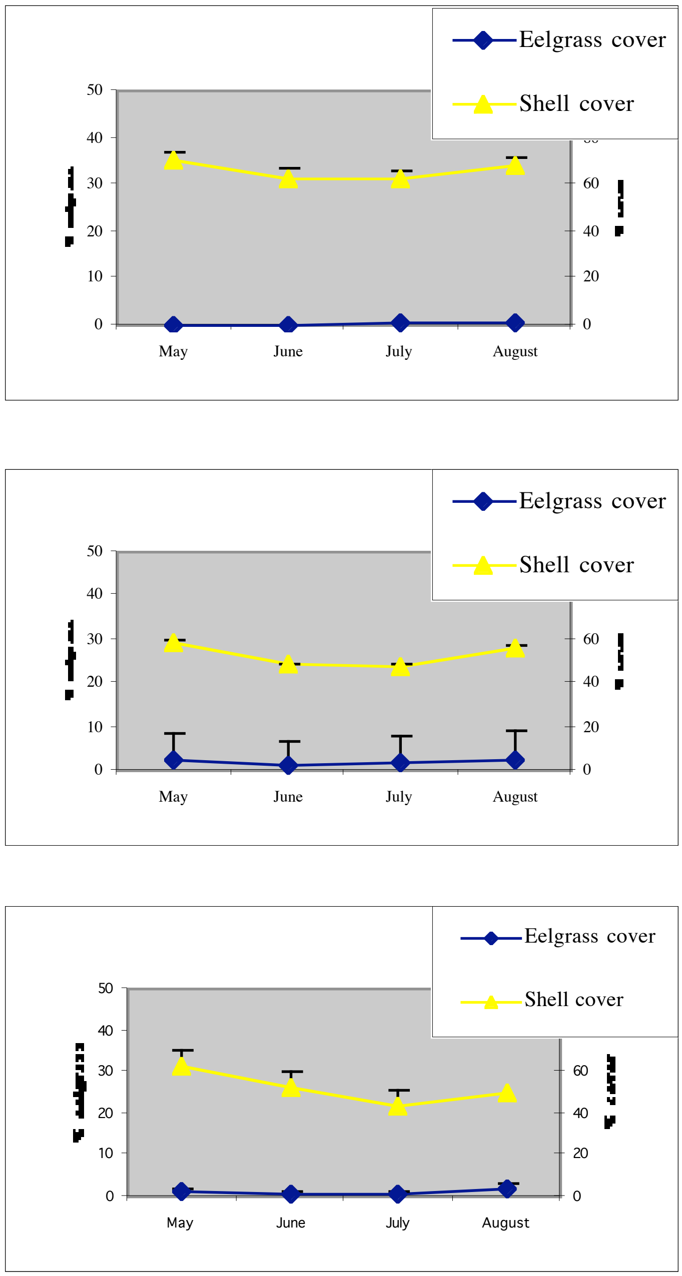


Figure 22. Eelgrass and shell cover data for the new 2003 shell plots: Up, Down, and East.

Mortality rates

Although the three new shell plots produced the most crabs, mortality rates on these plots were not consistently lower than for old shell plots sampled this year (Table 4). Surprisingly, the 2003 Up plot where production rates were the best, had only the 4th highest survival rate out of 9. In general, crabs survived better on new shell (average rank for new plots was 3.3 compared to 5.8 for old plots), but mortality rate differences do not help explain the 2003 production trends, particularly not among the three new shell plots.

Table 4. Mortality rates and percent survival for Dungeness crab on the nine plots sampled during summer 2003.

Plot	z	% survival	Rank
1995 Island	0.0211	47.71	2
1995 Mainland	0.0217	46.86	3
1996/1997	0.0390	25.55	9
1997 East	0.0268	39.18	6
2000 Up	0.0368	27.55	8
2000 East	0.0280	37.51	7
2003 Up	0.0242	42.88	4
2003 Down	0.0174	54.36	1
2003 East	0.0244	42.63	5

Mortality rates for 2003 summer on new shell are comparable to past years (Table 5), but those on old shell are lower than expected (although within one standard deviation from the mean). Interestingly, the standard deviation for mortality rates on old shell plots is almost twice that of new shell plots (0.0076 compared to 0.0043). This is opposite the trend for production • m^{-2} where variability is much greater among nw shell plots (Figure 9).

Table 5. Annual mortality rates for new and old shell plots. Survival is the percent of crab juvenile J2 instars surviving through the 35 day interval to the J4 stage when exodus to subtidal areas occurs.

Year	New shell	% Survival	Old Shell	% Survival
1990	0.0195	50.54	N/A	
1991	0.0276	38.06	0.0216	46.95
1992	0.0179	53.45		
1993	N/A		0.0216	46.95
1994	0.0187	51.97	0.0216	46.95
1995	0.0136	62.13	0.0248	41.98
1996	0.0123	65.02	0.0096	71.46
1997	0.0158	57.52	0.0187	51.97
1998	0.0208	48.29	0.0343	30.10
1999	0.0168	55.54	0.0226	45.34
2000	0.0216	46.95	0.0197	50.18
2001	N/A		0.0321	32.51
2002	N/A		0.0098	70.96
2003	0.0220	46.32	0.0289	36.37
Average	0.0188	52.34	0.0221	47.65
Std dev	0.0043	7.6408	0.0076	12.9294

Summary and Conclusions

The three new 2003 shell plots: 2003 Up, 2003 Down, and 2003 East) performed quite well, yielding 0.91, 0.64, and 0.47 million J4 crabs respectively over the four month sampling period in summer 2003. All three new plots outperformed all old shell plots; the 1995 Island plot had the next highest productivity with 0.24 million crabs. Total production during the 2003 season, summed across all plots sampled, was the third highest in the 14 year history of the project. The 2.81 million crabs produced this year follows 2000 (which yielded 3.42 million J4 crabs) and 1992 (which yielded 3.23 crabs). This brings the cumulative sum of J4 individuals produced by Grays Harbor mitigation plots to 20.89 million since its inception in 1990.

Production rate per square meter of habitat created was also quite good for 2003 plots. The three new plots produced an average of 30 crabs •m^{-2} and half of the old shell plots also exceeded the initial mitigation target of 10 crabs • m^{-2}. Shell cover still correlates extremely well with production rate, particularly shell cover values for May and June when crab densities are the highest; the three poorest performing plots were ones with the lowest average May and June percent shell cover values.

Hemigrapsus oregonensis densities were extremely low again this season, and ecology and thus interspecific competition for refuge spaces seems to be a minor factor among juvenile Dungeness crabs on the shell mitigation plots. Eelgrass distribution and coverage does not help explain the trends in production data at this point, but a longer timeline of data may help predict where optimal shell placement sites will be.

Plot-specific mortality rates do not explain the production variation among new shell plots for the 2003 season, although in general survival rates were better on new habitat. The three new shell plots received ranks 1, 4, and 5 out of 9 for best survival. Settlement patterns seem to be the key to the production results seen this year: The highest performing plot, 2003 Up, had densities of over 70 crabs • m^{-2} in May, and almost 150 crabs • m^{-2} in June. The 2003 Down plot, yielding the second highest number of J4 crabs, had over 60 crabs • m^{-2} in May and almost 80 crabs • m^{-2} in June (as well as the best survival rate of all plots sampled this year). The 2003 East plot had densities of about 170 crabs • m^{-2} in May dropping to just over 60 in June, but survival was only 42.6%, the lowest of the three new shell plots. Elevation of shell habitat may partially explain the settlement preferences or initial density differences as the highest elevation was the 2003 Up plot. This relationship continues to be one to watch as new data comes in.

By 2004 and 2005, we should have enough information to determine whether the overlay strategy proves to be an improvement over the previous strategy. Data will then be available to compare shell longevity directly between plots and to compare productivity between overlay plots and those created on bare mud substrate with no shell basement from previous mitigation efforts. During its initial year, the overlay shell looks similar to past placement strategies, but it is one year and greater post-construction that differences in shell longevity generally affect habitat quality.

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